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Situational Lightning Climatologies for Central Florida: Phase V

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Executive Summary

The threat of lightning is a daily concern during the warm season in Florida. Research has revealed distinct spatial and temporal distributions of lightning occurrence that are strongly influenced by large-scale atmospheric flow regimes (Lericos et al. 2002). The 45th Weather Squadron (45 WS), Spaceflight Meteorology Group (SMG) and National Weather Service in Melbourne, FL (NWS MLB) have the responsibility of issuing weather forecasts for airfields located in central Florida. Until the end of the Space Shuttle Program, SMG and 45 WS shared forecasting responsibility for the Shuttle Landing Facility depending on the mission. The 45 WS has forecasting responsibility for the Cape Canaveral Air Force Station (CCAFS) Skid Strip and Patrick Air Force Base (PAFB) while the NWS MLB is responsible for issuing terminal aerodrome forecasts (TAF) for airports throughout central Florida.

As in the previous phase, the climatologies included the probability of lightning at 5-, 10-, 20- and 30-NM distances from the center point of the runway at each site and the climatologies were stratified by flow regimes with probabilities depicted at 1-, 3-, and 6-hr intervals. In this phase, the AMU added three years of data resulting in a period of record (POR) for the warm season months from 1989-2010. This phase added 27 sites to the existing 9-site database and included the CCAFS Skid Strip, PAFB and 25 commercial airports. Sites were added to provide the NWS MLB with lightning climatologies for the sites for which they provide backup support, some to support the NWS offices in Jacksonville, Tampa and Miami and some for other 45 WS sites. Also new in this phase was the addition of a moisture stratification based on precipitable water (PWAT) and a stability stratification based on Thompson Index (TI) derived from sounding data at four Florida radiosonde locations. Larger PWAT and TI values represent a more unstable atmosphere. The moisture and stability stratifications were added to separate more active from less active lighting days within the same flow regime.

The 14th Weather Squadron (14 WS) Strategic Climatic Information Service provided National Lightning Detection Network (NLDN) cloud-to-ground lightning strike data to the 45th Weather Squadron for use by the AMU staff for this work. The NLDN database contains lightning flash data provided to the 14 WS by Vaisala Inc., in Tucson AZ. The 14 WS customized the dataset for the AMU and provided files that included the date, time, latitude and longitude, peak current, number of strokes (more commonly known as multiplicity), polarity, number of detectors, bearing and distance of every flash within a 30 NM radius of the center of the runway for each site and included the years 1989-2010. The use of lightning flash data, versus lightning stroke data, was sufficient for this application.

The results were presented in tabular and graphical format and incorporated into a web-based GUI so forecasters could easily navigate through the large amount of data. The GUI's HyperText Markup Language format makes it usable in most web browsers on computers with different operating systems. The AMU delivered two GUI's to the customers – one with the additional PWAT stratification and one with both the PWAT and TI stratifications. This was done because the results with both PWAT and TI stratifications added to the dataset yielded some combinations with insufficient sample size.

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1. Introduction

The threat of lightning is a daily concern during the warm season in Florida. Research has revealed distinct spatial and temporal distributions of lightning occurrence that are strongly influenced by large-scale atmospheric flow regimes (Lericos et al. 2002). The 45th Weather Squadron (45 WS), Spaceflight Meteorology Group (SMG) and National Weather Service in Melbourne, FL (NWS MLB) have the responsibility of issuing weather forecasts for airfields located in east-central Florida. Until the end of the Space Shuttle Program, the SMG and 45 WS shared forecasting responsibility for the SLF depending on the mission. The 45 WS has forecasting responsibility for the Cape Canaveral Air Force Station (CCAFS) Skid Strip and Patrick Air Force Base (PAFB) while the NWS MLB is responsible for issuing terminal aerodrome forecasts (TAFs) for airports throughout east-central Florida within their County Warning Area (CWA).

In the previous phase of this project (Bauman 2009), the AMU calculated lightning climatologies for the SLF and eight other airfields in central Florida based on a 19-year record of cloud-to-ground (CG) lightning data from the National Lightning Detection Network (NLDN) for the warm season months of May through September (1989-2007). The climatologies included the probability of lightning at 5-, 10-, 20- and 30-NM distances from the center point of the runway at each site. The climatologies were stratified by lightning flow regimes for peninsular Florida with probabilities depicted at 1-, 3-, and 6-hr intervals.

This phase updates the previous work by adding 27 sites to the 9-site database including the CCAFS Skid Strip, PAFB and 25 commercial airports (Figure 1). It also adds three years of NLDN data resulting in a period of record (POR) for the warm season months from 1989-2010. In addition to the flow regime stratification, a moisture stratification based on precipitable water (PWAT) and a stability stratification based on Thompson Index (TI) were derived from sounding data at four Florida radiosonde locations (Figure 2) and were added to separate more active from less active lighting days within the same flow regime. Larger PWAT and TI values represent a more unstable atmosphere.

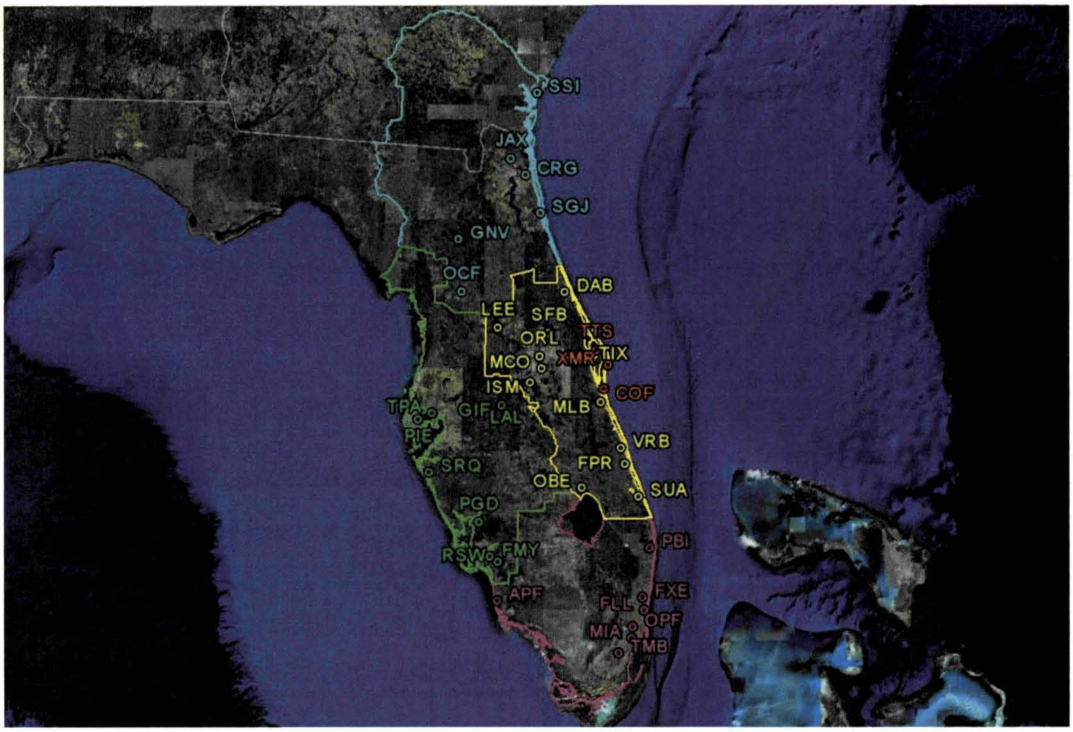


Figure 1. Map of Florida showing location of thirty-six airport sites in four NWS CWAs. Yellow represents the NWS MLB, cyan the Jacksonville NWS, green the Tampa NWS and magenta the Miami NWS. The red sites within the NWS MLB CWA are the responsibility of the 45 WS and SMG.

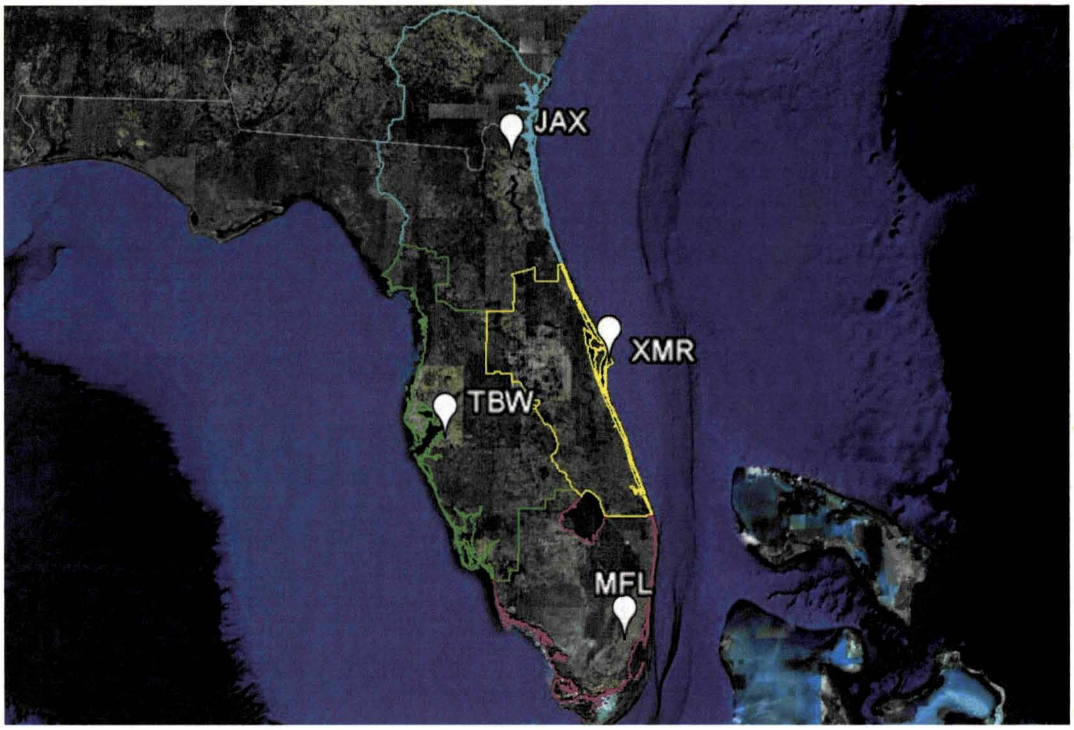


Figure 2. Map of Florida showing the locations of the four sounding sites used to derive PWAT and TI values. The color outlines correspond to the NWS CWAs as in Figure 1.

The eight airfields in the previous phase represented the most important of the primary NWS MLB sites as well as the SLF for space shuttle and other operations in the KSC/CCAFS area. For this phase, the NWS MLB requested the AMU expand the number of sites to include all of the TAF sites in the NWS MLB CWA plus the sites for which they have backup TAF responsibility for the NWS in Tampa (NWS TBW) CWA. The 45 WS requested adding the CCAFS Skid Strip and PAFB to support their aviation operations. These requests resulted in creating situational lightning climatologies for a total of 12 additional sites (21 total sites). Three months into the task, the AMU realized the data processing was proceeding faster than expected and asked the customers if there were any other sites that could be added to the climatology. The NWS MLB requested 13 additional sites for the NWS in Jacksonville (NWS JAX), the NWS in Miami (NWS MFL) and NWS TBW bringing the total to 34 sites. In May 2011, NWS Headquarters added TAF responsibility for two airfields, Lakeland and Punta Gorda, in the TBW CWA beginning 1 October 2011. The NWS MLB requested that the AMU add these two sites to the lighting climatologies thereby bringing the total number of sites to 36. Table 1 lists all of the airfields and their affiliated forecast agencies. The AMU was able to accommodate the additional sites and keep within the budgeted schedule because they had modified the data processing scripts to maximize efficiency. By making the graphical user interface and data available to NWS JAX, NWS MFL and NWS TBW, the lightning climatologies produced from this task will not only support space operations at KSC and CCAFS but will support military, commercial and some general aviation at airfields from southeastern Georgia to southern Florida.

Table 1. List of airfields and affiliated forecast agencies.

NWS MLB	45 WS/SMG	NWS JAX	NWS TBW	NWS MFL
Daytona Beach	SLF	Craig	Fort Meyers	Ft. Lauderdale-Hollywood
Fort Pierce	CCAFS Skid Strip	Gainesville	Ocala	Ft. Lauderdale Exec
Kissimmee	PAFB	Jacksonville	Sarasota-Bradenton	Kendall
Leesburg		Malcolm McKinnon (GA)	St. Petersburg	Miami
Melbourne		St. Augustine	Southwest Florida	Naples
Orlando Exec			Tampa	Opa-Locka
Orlando Int'l			Winter Haven	Palm Beach
Okeechobee			Lakeland	
Sanford			Punta Gorda	
Stuart				
Titusville				
Vero Beach				

2. Data

Three types of data were needed for this task: the individual lightning strike data from NLDN, the dates on which each flow regime occurred, and sounding data to calculate the PWAT & TI values. The AMU obtained the NLDN CG lightning strike data from the 14th Weather Squadron (14 WS) in Asheville, NC with assistance from the 45 WS. The flow regime days through 2007 were obtained from an earlier AMU task described in Lambert (2007). The AMU determined the flow regime days for 2008-2010 using the same methodology as in Lambert (2007). The sounding data for JAX, TBW and MFL were downloaded from the National Oceanic and Atmospheric Administration/Earth System Research Laboratory (NOAA/ESRL) Radiosonde Database website (http://www.esrl.noaa.gov/raobs/). The sounding data for XMR was provided to the AMU by the Eastern Range Technical Services Contractor, Computer Sciences Raytheon (CSR). The PWAT & TI values were calculated from the soundings taken at the four sites shown in Figure 2.

The POR for the data set varied based on availability of sounding data to calculate PWAT. The POR and sounding location used to derive PWAT and TI associated with each site is summarized in Table 2.

Table 2. List of airfields and associated sounding locations used to determine POR, PWAT and TI.

XMR May 1989-Sep 2010	TBW May 1994-Sep 2010	JAX May 1994-Sep 2010	MFL May 1995-Sep 2010
CCAFS Skid Strip	Fort Meyers	Craig	Ft. Lauderdale-Hollywood
Daytona Beach	Gainesville	Jacksonville	Ft. Lauderdale Exec
Fort Pierce	Ocala	Malcolm McKinnon (GA)	Kendall
Kissimmee	Sarasota-Bradenton	St. Augustine	Miami
Leesburg	St. Petersburg		Naples
Melbourne	Southwest Florida		Opa-Locka
Orlando Exec	Tampa		Palm Beach
Orlando Int'l	Winter Haven		
Okeechobee	Lakeland		
PAFB	Punta Gorda		
Sanford			
SLF			
Stuart			
Titusville			
Vero Beach			

2.1 Lightning Data

The AMU downloaded the NLDN data files from the 14 WS as requested by the 45 WS. The NLDN database contained lightning flash data provided to the 14 WS by Vaisala, Inc. in Tucson, AZ. The 14 WS provided data that included date, time, latitude and longitude, peak current, number of strokes (more commonly known as multiplicity), polarity, number of detectors, bearing and distance of every flash within a 30 NM radius of the center of the runway for each site for the entire POR.

The 14 WS produced 36 data files (one for each site) in comma separated value (.csv) format ranging in size from 88 to 186 MB per file. The files were too large to open in Microsoft Excel™ 2010 but the AMU was able to open and process the files with S-PLUS® software (Insightful Corporation 2007).

2.2 Flow Regimes

The flow regime classification method (Table 3) was unchanged from the previous phase of this work (Bauman 2009) and was based on Lambert (2007) which included using the 1000–700 mb mean wind direction in the 1000 UTC XMR sounding. The XMR 1000–700 mb mean wind direction was used to assign flow regimes if classified as 'Other' by the MFL, TBW, and JAX soundings. This reduced the 'Other' classifications considerably. At this point it is important to note that the nomenclature used to describe these flow regimes was based on the subtropical ridge position relative KSC/CCAFS. Therefore, forecasters using this lightning climatology at other locations should determine their flow regime based on the location of the subtropical ridge and not based on the AMU naming convention. For example, consider airfields on the east coast of south Florida under the AMU naming convention SW-2 flow regime which defines the subtropical ridge location north of MFL and south of TBW. While the winds at KSC/CCAFS must be southwest in this scenario, the winds could be anywhere between southwest and southeast at airfields north of MFL and south of KSC/CCAFS, depending on the exact position of the subtropical ridge on that particular day. Table 3 is available in the help page of the GUI to assist forecasters with the AMU naming convention and flow regime definition.

Table 3. Flow regimes as reclassified in Lambert (2007), a brief definition of each flow regime, the corresponding sectors showing the average 1000 – 700 mb wind directions at each of the stations, and the number of days in each regime during the warm seasons in 1989–2010.

AMU Naming Convention	Flow Regime Definition	Rawinsonde Station MFL	TBW	JAX	# Days in Regime	% of Total Days
SW-1	Subtropical ridge south of MFL. Southwest flow over KSC/CCAFS.	180°-270°	180°-270°	180°-270°	388	12
SW-2	Subtropical ridge north of MFL, south of TBW. Southwest flow over KSC/CCAFS.	90°-180°	180°-270°	180°-270°	819	25
SE-1	Subtropical ridge north of TBW, south of JAX. Southeast flow over KSC/CCAFS	90°-180°	90°-180°	180°-270°	563	17
SE-2	Subtropical ridge north of JAX. Southeast flow over KSC/CCAFS.	90°-180°	90°-180°	90°-180°	317	10
NE	Northeast flow over Florida, likely from a stronger-than-average subtropical ridge north of JAX extending into southeast U.S., at times forming a closed high pressure center.	0°-90°	0°-90°	0°-90°	426	13
NW	Northwest flow over Florida, likely from a stronger-than-average subtropical ridge south of MFL extending into Gulf of Mexico.	270°-360°	270°-360°	270°-360°	401	12
Other	When the layer-averaged wind directions at the three stations did not fit in defined flow regime.				381	11
All	Non-flow regime based (e.g., all days from all years in the warm season included)				3295	

From previous AMU work, the flow regime files were available in Excel format through 2007. The AMU created 2008, 2009 and 2010 flow regime files by first downloading NWS sounding data from the NOAA/ESRL for JAX, TBW, MFL and XMR. The existing S-PLUS scripts were updated and tested and then used to create the new warm season flow regime files for the entire POR which were exported from S-PLUS into Excel format for later use.

2.3 Sounding Data

2.3.1 PWAT

The AMU derived PWAT values using the closest sounding relative to each site as shown in Table 2. The PWAT stratification threshold values varied by up to 13% among the four sounding locations in any given warm season month. The values were derived from climatological PWAT plots created by Mr. Matthew Bunkers, the Science and Operations Officer (SOO) at the Rapid City, SD NWS Forecast Office (http://www.crh.noaa.gov/unr/?n=pw). Plots for the four sounding sites used in this work are shown in Figure 3. Based on discussions with Mr. Dave Sharp, the SOO at NWS MLB, values below the 25th percentile would be considered low, values above the 75th percentile would be considered high and the values between them and inclusive would be considered average. This is consistent with application of nonparametric statistics. Table 4 shows the PWAT stratifications from the four sounding sites for the warm season months.

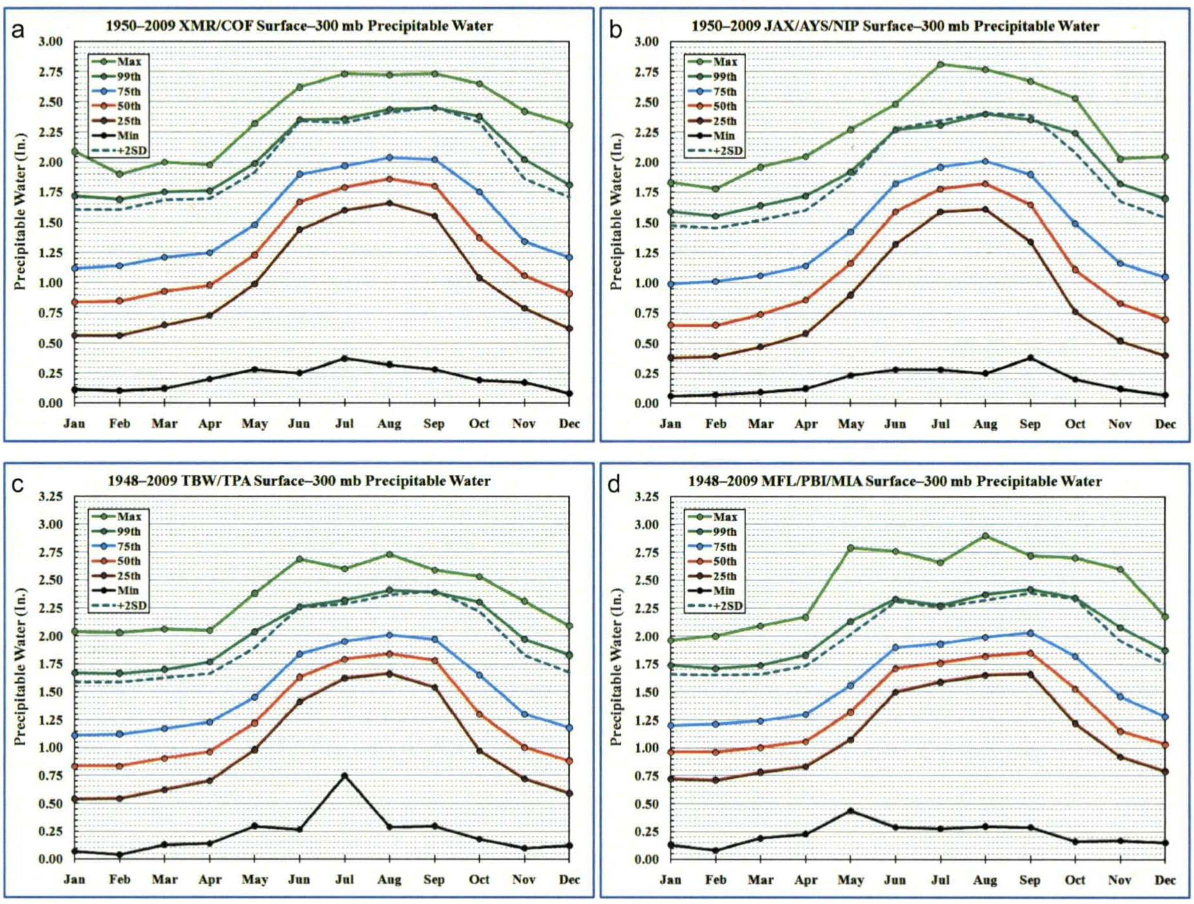


Figure 3. Plots of climatological PWAT from surface to 300 mb for the four sounding sites used in this work: a) XMR (1950-2009), b) JAX (1950-2009), c) TBW (1948-2009) and d) MFL (1948-2009). The "low" threshold used to stratify this data is represented the 25th percentile (brown curves) and the "high" threshold is represented by the 75th percentile (cyan curves).

Table 4. The PWAT stratification thresholds for the warm season months from the four sounding sites. The low values represent the 25th percentile and the high values the 75th percentile from the dataset with the medium values falling between the two.

XMR				JAX			
Month	Low	Average	High	Month	Low	Average	High
May	< 1.00"	1.00" to 1.50"	> 1.50"	May	< 0.90"	0.90" to 1.40"	> 1.40"
Jun	< 1.45"	1.45" to 1.90"	> 1.90"	Jun	< 1.30"	1.30" to 1.80"	> 1.80"
Jul	< 1.60"	1.60" to 1.95"	> 1.95"	Jul	< 1.60"	1.60" to 1.95"	> 1.95"
Aug	< 1.65"	1.65" to 2.05"	> 2.05"	Aug	< 1.60"	1.60" to 2.00"	> 2.00"
Sep	< 1.55"	1.55" to 2.00"	> 2.00"	Sep	< 1.35"	1.35" to 1.90"	> 1.90"
TBW				**MFL**			
Month	Low	Average	High	Month	Low	Average	High
May	< 1.00"	1.00" to 1.45"	> 1.45"	May	< 1.05"	1.05" to 1.55"	> 1.55"
Jun	< 1.40"	1.40" to 1.85"	> 1.85"	Jun	< 1.50"	1.50" to 1.90"	> 1.90"
Jul	< 1.60"	1.60" to 1.95"	> 1.95"	Jul	< 1.60"	1.60" to 1.95"	> 1.95"
Aug	< 1.65"	1.65" to 2.00"	> 2.00"	Aug	< 1.65"	1.65" to 2.00"	> 2.00"
Sep	< 1.55"	1.55" to 1.95"	> 1.95"	Sep	< 1.65"	1.65" to 2.05"	> 2.05"

The PWAT values were not readily available in the raw sounding data and needed to be derived. To do so, the AMU calculated vapor pressure (e) and then the mixing ratio (w) in S-PLUS using the following standard equations:

$$e = 6.11 \times 10^{\frac{7.5 \times T_d}{237.7 + T_d}}$$

$$w = 621.97 \times \frac{e}{p - e}$$

Where:

T_d = Dew point temperature
p = Pressure

The PWAT was then derived in S-PLUS by summing up the mixing ratios between pressure levels from surface to 300 mb using the following standard PWAT equation:

$$PWAT = \frac{1}{g} \int_{p_1}^{p_2} w dp$$

Where:

g = Acceleration of gravity
p_1 = Lower pressure level in the layer
p_2 = Upper pressure level in the layer

2.3.2 TI

The AMU updated the S-PLUS scripts that had been modified to calculate the PWAT stratification to include the TI stratification. The TI threshold values were adopted from previous AMU work to include the Objective Lightning Probability Forecasting for Kennedy Space Center and Cape Canaveral Air Force Station, Phase II (Lambert 2007), the Severe Weather Forecast Decision Aid (Bauman et. al. 2005) and the Upgrade Summer Severe Weather Tool (Watson 2011). In these tasks, the AMU found that the TI was one of the best indicators of lightning occurrence and reported severe weather events during the warm season months. The 45 WS has also found the TI to be one of the best thunderstorm predictors. However, the climatological TI stratification thresholds were not determined for each month like the PWAT values

were. Therefore, the TI thresholds are representative of the entire warm season based on the XMR sounding. The thresholds were adopted primarily from the TI values in the Severe Weather Forecast Decision Aid and the Upgrade Summer Severe Weather Tool. The POR for the TI values was the warm season months from 1989-2010. The TI stratification thresholds are:

- Low: $TI < 25$
- Average: $25 \leq TI \geq 34$
- High: $TI > 35$

Like the PWAT values, the TI values were not readily available in the raw sounding data and had to be calculated. The TI is derived by subtracting the Lifted Index (LI) stability parameter from the K-Index (KI) stability parameter, which the AMU calculated from the raw sounding data in S-PLUS using the following standard equations:

$$KI = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700})$$

Where:

T_{850} = 850 mb temperature

T_{500} = 500 mb temperature

T_{700} = 700 mb temperature

T_{d700} = 700 mb dew point temperature

$$LI = (T_{500} - T^*)$$

Where:

T^* = Temperature of a parcel characterized by the mean T_d in the lowest 3000ft and the forecast maximum surface temperature if it were lifted dry adiabatically to saturation and then moist adiabatically to 500 mb.

The TI was then derived in S-PLUS by subtracting LI from KI using the following standard TI equation:

$$TI = KI - LI$$

3. Data Processing

The majority of the effort for this task involved combining the raw NLDN and flow regime data files with moisture and stability stratifications into formats easily manipulated by the software packages used to analyze the data. The end goal of the data processing was to output the statistics in a format that could be implemented in a graphical user interface (GUI).

3.1 Lightning Files

The 14 WS provided one .csv format file per site containing NLDN CG lightning strike data within 30 NM of the center of the runway for each site. The file for each site contained the date, time, latitude and longitude, peak current, number of strokes (more commonly known as multiplicity), polarity, number of detectors, bearing and distance of every flash within a 30 NM radius of the center of the runway for each site for the entire POR. Normally a .csv-formatted file can be opened as a spreadsheet in Excel, but each file surpassed the 1,048,576 row limit imposed by Excel 2010. Therefore, the AMU imported the .csv files into the S-PLUS software package to process the lightning data files. Upon doing so, S-PLUS reformatted the files into a proprietary format that uses an object class called a data frame to store matrix shaped data. A sample S-PLUS data frame containing NLDN data from an imported .csv file is shown in Figure 4. These data were then manipulated using the S-PLUS scripting language. Since only the warm season months of May-September were of interest for this task, the AMU first extracted the warm season months from each file. Using the new files containing only warm season NLDN data, the AMU processed each site's file and sorted them by year, month and day to prepare them to be merged with the flow regime data.

Year	Month	Day	Hour.UTC.	Minute	Second	Latitude	Longitude	PeakCurrent	Stokes	Polarity	Detectors	Bearing	Distance.NM.
2008.00	7.00	11.00	19.00	38.00	8.31	28.73	-80.99	7.90	1.00	N	2.00	305.46	27.42
2008.00	7.00	11.00	19.00	39.00	52.73	28.71	-81.01	42.20	4.00	N	4.00	301.92	27.25
2008.00	7.00	11.00	19.00	43.00	22.70	28.70	-80.99	17.60	1.00	P	8.00	301.42	26.37
2008.00	7.00	11.00	19.00	45.00	28.65	28.77	-80.99	11.20	1.00	N	4.00	309.38	28.96
2008.00	7.00	4.00	19.00	47.00	48.69	28.50	-81.11	10.90	1.00	N	7.00	274.11	28.90
2008.00	7.00	4.00	20.00	11.00	57.90	28.45	-81.05	7.50	1.00	N	4.00	267.45	25.27
2008.00	7.00	4.00	20.00	15.00	18.22	28.36	-81.03	14.50	1.00	N	7.00	254.77	25.31
2008.00	7.00	4.00	20.00	16.00	11.75	28.41	-81.00	16.60	7.00	N	7.00	261.30	22.99
2008.00	7.00	4.00	20.00	19.00	7.19	28.45	-81.02	12.90	3.00	N	6.00	267.31	24.06
2008.00	7.00	4.00	20.00	19.00	45.86	28.45	-81.00	3.80	1.00	N	2.00	266.87	23.01
2008.00	7.00	4.00	20.00	20.00	13.54	28.40	-81.04	15.70	9.00	N	3.00	260.68	25.12
2008.00	7.00	4.00	20.00	22.00	28.77	28.36	-81.06	17.80	1.00	N	7.00	256.25	26.94
2008.00	7.00	4.00	20.00	22.00	32.05	28.39	-81.02	14.70	2.00	N	7.00	259.56	24.13
2008.00	7.00	4.00	20.00	22.00	53.81	28.48	-81.12	4.10	1.00	N	2.00	271.12	29.31
2008.00	7.00	4.00	20.00	24.00	28.19	28.39	-81.04	25.90	3.00	N	6.00	259.33	25.22
2008.00	7.00	4.00	20.00	25.00	12.15	28.43	-81.03	8.70	1.00	N	3.00	264.27	24.53
2008.00	7.00	4.00	20.00	25.00	14.46	28.41	-81.06	14.70	3.00	N	6.00	261.97	26.09
2008.00	7.00	4.00	20.00	25.00	24.85	28.38	-81.02	24.00	8.00	N	8.00	257.85	24.49
2008.00	7.00	4.00	20.00	25.00	53.65	28.42	-81.01	23.10	4.00	N	7.00	263.48	23.72

Figure 4. Sample S-PLUS data frame containing NLDN data after it was imported from a .csv file.

3.2 Flow Regime Files

The flow regime data were contained in five Excel spreadsheet files each representing one warm season month. Each of the five files contained three columns of data with year, day and flow regime. Figure 5 shows a sample Excel file containing flow regime data from each July in the POR. To prepare these files for merging with the lightning data, the AMU imported the files into S-PLUS as data frames and wrote an S-PLUS script to insert a column representing the numeric month into each file, merged the five files and then sorted the new file based on year, month and day.

Year	Day	Regime
1989	1	Other
1989	2	NE
1989	3	Other
1989	4	NW
1989	5	Other
1989	6	SW-2
1989	7	SE-1
1989	8	SE-1
1989	9	SE-1
1989	10	SE-1
1989	11	NE
1989	12	NW
1989	13	SW-2
1989	14	SW-2
1989	15	SW-1
1989	16	SW-1
1989	17	SW-1
1989	18	SW-2
1989	19	SW-2
1989	20	SW-2
1989	21	SE-1
1989	22	SE-2
1989	23	SE-2
1989	24	SE-2
1989	25	NE
1989	26	NE
1989	27	Other
1989	28	SW-2
1989	29	NW
1989	30	SW-1

FlowReg.Predictor.New.Jul

Figure 5. Sample Excel file containing flow regime data from July.

3.3 Sounding Files

The PWAT and TI parameters were derived from soundings taken at the four radiosonde sites shown in Figure 2. The sounding files from JAX, TBW and MFL downloaded from NOAA/ESRL were in "FSL format (ASCII text)" format (Figure 6a). The sounding files from XMR provided by CSR were in an ASCII text format different than the NOAA/ESRL format (Figure 6b). Therefore, the AMU wrote two ingest scripts in S-PLUS that created files in data frame format which were then reformatted so they could be merged with the lightning files and flow regime files for further processing.

a
```
 254      12       1      SEP    2010
   1   13889   72206  30.43N 81.70W     10   1126
   2     100     118    1230    127  99999      3
   3             JAX                 99999     kt
   9   10160      10     224    214    325      3
   5   10110      53     220    211  99999  99999
   5   10030     122     250    238  99999  99999
   4   10000     148     250    232     55      9
   5    9930     209     250    227  99999  99999
   6    9823     304   99999  99999     70     13
   6    9486     609   99999  99999     85     12
   4    9250     829     194    194     85     14
   6    9158     914   99999  99999     80     15
   5    9130     940     182    182  99999  99999
   5    9010    1053     184    177  99999  99999
   6    8836    1219   99999  99999     90     22
   5    8750    1302     166    161  99999  99999
   5    8680    1370     166    136  99999  99999
   5    8590    1458     162    114  99999  99999
   4    8500    1555     166     66     80     27
   5    8460    1595     170     30  99999  99999
   5    8300    1757     180    -40  99999  99999
   6    8230    1828   99999  99999     80     30
   6    7938    2133   99999  99999     80     31
   5    7790    2292     140    -60  99999  99999
   6    7655    2438   99999  99999     75     34
   6    7380    2743   99999  99999     90     24
   5    7310    2823     116   -134  99999  99999
   6    7115    3048   99999  99999     80     21
   5    7020    3159     112   -148  99999  99999
   4    7000    3191     110   -160    100     18
```

b
```
RAWINSONDE AMP/LR
CAPE CANAVERAL AFS, FLORIDA
1010Z 01 SEP 2007

   ALT  DIR    SPD   SHR     T     TD      PRE  RH    AH      DEN   IR   VS   VPS  PW
GEOMFT  DEG     KT    PS     C      C       MB   %  GPM3     GPM3    N   KT    MB  MM

    16  200    2.0 0.000  23.2   21.6  1013.50  91 18.82  1179.97  375  673 25.74   0
  1000  206   11.2 0.016  25.7   20.1   979.72  71 17.10  1131.67  353  676 23.58   6
  2000  234    7.1 0.010  23.9   19.6   946.45  77 16.62  1099.87  344  674 22.79  11
  3000  223    6.1 0.003  21.6   18.4   914.09  82 15.60  1070.91  332  671 21.21  16
  4000  222    6.5 0.001  19.5   17.0   882.60  85 14.34  1041.93  318  669 19.36  21
  5000  252    8.8 0.008  18.1   14.2   851.98  78 12.09  1011.74  298  667 16.25  25
  6000  243    8.7 0.002  16.3   12.2   822.25  77 10.67   983.15  284  665 14.26  28
  7000  235    7.1 0.003  14.5   11.6   793.37  83 10.28   954.60  276  663 13.64  32
  8000  209    6.8 0.005  12.8   10.2   765.34  84  9.46   926.67  265  661 12.48  35
  9000  224    6.1 0.003  11.0    9.2   738.13  89  8.90   899.55  256  659 11.67  37
 10000  250    6.3 0.005   9.7    7.0   711.74  83  7.66   871.97  242  656  9.99  40
 11000  252    5.8 0.001   8.6    5.3   686.18  80  6.86   844.27  231  656  8.92  42
 12000  248    8.1 0.004   6.9    3.2   661.40  77  5.94   819.16  220  654  7.67  44
 13000  255    7.8 0.002   5.0    1.2   637.36  77  5.21   795.12  210  650  6.68  46
 14000  262    9.5 0.003   2.9    0.8   614.03  86  5.08   771.82  204  649  6.47  48
 15000  271   10.7 0.003   1.0   -0.1   591.39  92  4.78   748.60  197  647  6.04  49
 16000  269   11.1 0.001  -0.4   -2.1   569.43  88  4.17   724.78  188  645  5.25  50
 17000  284   11.6 0.005  -1.6   -5.2   548.19  77  3.32   701.27  178  643  4.16  52
 18000  280   13.2 0.003  -3.7   -6.6   527.63  80  3.00   680.35  171  641  3.73  53
 19000  283   10.6 0.004  -5.4   -9.5   507.69  73  2.41   659.10  163  639  2.98  53
 20000  286   10.7 0.001  -7.1  -10.2   488.38  78  2.29   638.11  157  636  2.81  54
 21000  300    8.8 0.005  -8.8  -12.0   469.68  77  1.99   617.77  151  634  2.43  55
 22000  294   11.8 0.005 -10.4  -15.5   451.61  66  1.51   597.87  143  632  1.83  55
 23000  291    9.9 0.003 -12.2  -18.7   434.10  58  1.16   578.83  137  630  1.40  56
 24000  305    3.7 0.011 -14.3  -19.0   417.14  67  1.14   560.73  133  628  1.36  56
```

Figure 6. Sample sounding file formats from a) NOAA/ESRL and b) CSR.

3.4 Merged and Output Files

First, with the lightning and flow regime files in similar formats, the AMU wrote an S-PLUS script to merge each site's 30 NM range lightning data files with the flow regime files. The resulting merged file for each site contained the 30 NM range lightning strike data and its corresponding flow regime for each day in the POR. Then the S-PLUS data frames containing each site's PWAT and TI were merged with the data frames containing the lightning and flow regime data. A sample merged data frame (Figure 7) shows the flow regime, PWAT and TI in the last three columns.

Year	Month	Day	Hour.UTC.	Minute	Second	Latitude	Longitude	PeakCurrent	Stokes	Polarity	Detectors	Bearing	Distance.NM.	Regime	PW	TI
1989.00	6.00	22.00	11.00	39.00	44.61	28.30	-80.04	58.60	1.00	N	2.00	109.98	29.44	SE-1	1.91	38.23
1989.00	7.00	22.00	11.00	28.00	20.70	28.32	-80.06	32.30	2.00	N	4.00	108.42	28.05	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	30.00	23.54	28.29	-80.09	39.30	1.00	N	4.00	113.10	27.50	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	23.00	21.10	28.28	-80.05	90.50	5.00	N	7.00	112.48	29.61	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	25.00	13.85	28.29	-80.07	47.50	6.00	N	7.00	112.07	28.55	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	27.00	30.34	28.30	-80.07	61.70	2.00	N	5.00	111.21	28.15	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	53.00	6.37	28.21	-80.15	34.10	2.00	N	4.00	124.70	26.67	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	50.00	57.49	28.16	-80.19	165.00	4.00	N	4.00	132.35	27.18	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	48.00	37.56	28.16	-80.15	68.00	5.00	N	6.00	129.86	28.65	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	49.00	19.42	28.17	-80.23	150.30	2.00	N	3.00	134.41	25.23	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	18.00	51.44	28.24	-80.06	141.10	4.00	N	5.00	117.02	29.95	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	23.00	37.46	28.38	-80.22	89.60	1.00	N	6.00	106.04	18.94	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	24.00	30.01	28.30	-80.08	59.30	4.00	N	6.00	111.14	27.74	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	50.00	58.95	28.17	-80.15	24.80	1.00	N	5.00	128.92	28.47	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	49.00	53.24	28.16	-80.15	62.50	3.00	N	7.00	129.87	28.93	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	47.00	22.83	28.16	-80.13	71.50	5.00	N	6.00	128.61	29.91	SE-2	1.86	34.32
1989.00	7.00	22.00	11.00	31.00	31.94	28.31	-80.14	54.50	2.00	N	5.00	113.07	24.50	SE-2	1.86	34.32
1989.00	8.00	13.00	11.00	11.00	3.10	28.71	-80.37	28.30	1.00	N	5.00	35.52	17.81	SE-2	1.74	32.13
1989.00	8.00	13.00	11.00	50.00	24.62	28.77	-80.46	44.10	2.00	N	5.00	16.51	19.18	SE-2	1.74	32.13
1989.00	8.00	19.00	11.00	29.00	54.32	28.95	-80.59	52.30	1.00	N	2.00	357.99	29.03	SE-1	1.95	39.13
1989.00	8.00	19.00	11.00	0.00	51.47	28.78	-80.88	40.20	1.00	N	7.00	318.44	25.01	SE-1	1.95	39.13
1989.00	8.00	19.00	11.00	7.00	58.48	28.72	-80.77	16.20	1.00	N	2.00	324.74	18.64	SE-1	1.95	39.13
1989.00	8.00	19.00	11.00	6.00	57.96	28.72	-80.75	45.20	4.00	N	6.00	327.12	17.98	SE-1	1.95	39.13
1989.00	8.00	19.00	11.00	4.00	53.08	28.81	-80.79	25.60	1.00	N	4.00	330.69	23.79	SE-1	1.95	39.13
1989.00	8.00	19.00	11.00	4.00	39.12	28.79	-80.75	45.50	2.00	N	4.00	333.24	21.55	SE-1	1.95	39.13
1989.00	8.00	19.00	11.00	3.00	40.63	28.52	-80.56	33.90	1.00	N	2.00	10.61	3.32	SE-1	1.95	39.13
1989.00	8.00	19.00	11.00	31.00	50.26	28.93	-80.59	70.40	3.00	N	2.00	357.66	27.48	SE-1	1.95	39.13
1989.00	8.00	26.00	11.00	57.00	34.60	28.94	-80.45	49.20	4.00	N	2.00	12.09	29.25	Other	2.03	36.33

Figure 7. Sample merged data frame showing the flow regime (Regime), PWAT (PW) and TI (TI) in the last three columns.

The AMU wrote S-PLUS scripts to extract 1-, 3- and 6-hourly interval data from the merged data frames resulting in three time-interval based merged data frames containing lightning flashes within 30 NM, flow regime, PWAT and TI stratifications for each site. Then, based on the 30-NM range data frames, the AMU wrote S-PLUS scripts to create 5-, 10- and 20-NM range data frames for each of the three time intervals. Finally, the data frames were stratified by month. However, the S-PLUS data frames are not compatible with the format needed to develop the GUI so the AMU wrote additional S-PLUS scripts to process and reformat the data frames and export them in Excel (.xls) format (Figure 8). This resulted in 3,780 Excel files per site and each file contained the number of lightning flashes stratified by distance, time interval, flow regime, PWAT threshold and TI threshold.

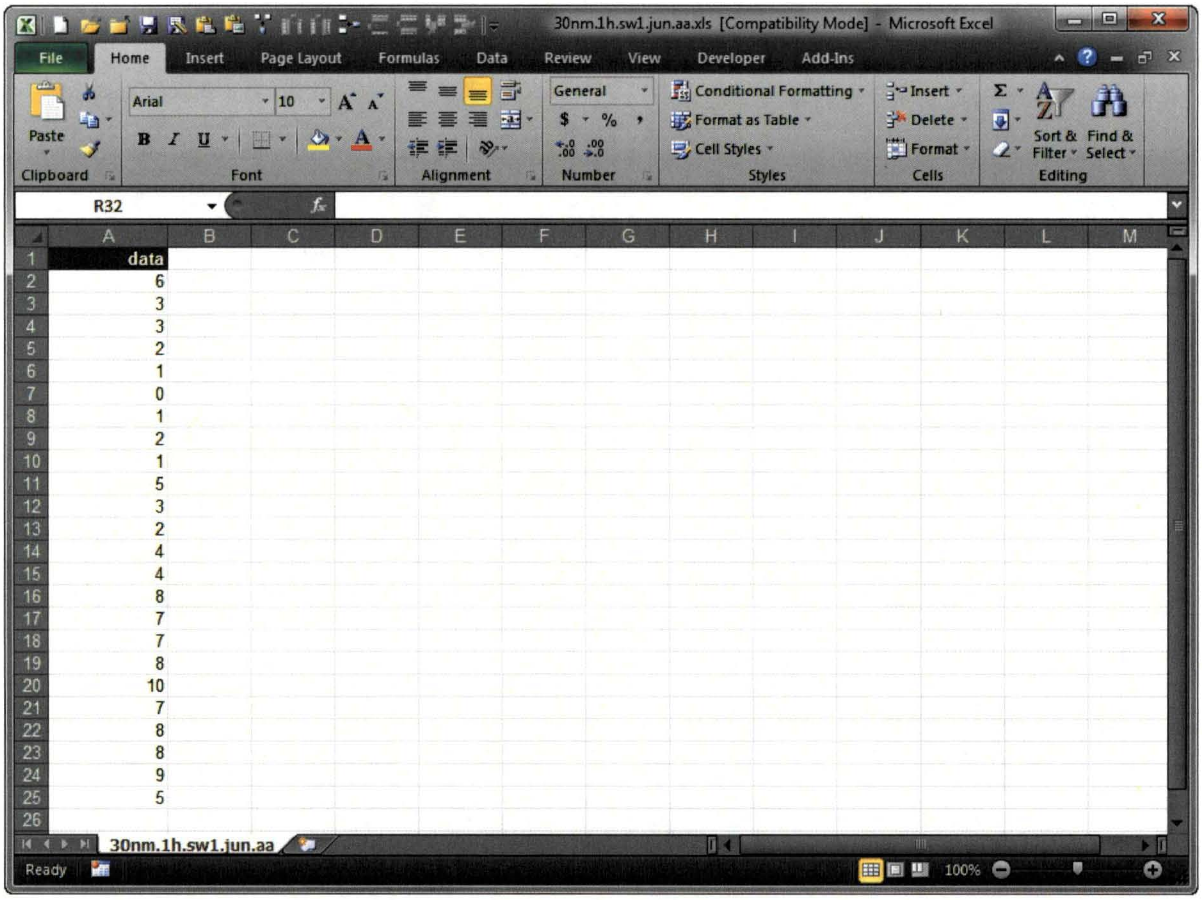


Figure 8. Sample Excel spreadsheet file exported by S-PLUS for the month of June and stratifications to include 30 NM range, 1-hour intervals, SW1 flow regime, average PWAT and average TI. Column A shows the number of days with lightning occurrence per hour at 1-hour intervals. Cell A2 represents 00-01 UTC and cell A25 represents 23-24 UTC.

4. GUI Development

The AMU developed a web-based HyperText Markup Language (HTML) GUI that can be used with most web browsers on computers with popular operating systems (e.g., Windows, Mac and Linux). Both NWS MLB and SMG indicated a web-based HTML GUI would be compatible with their operations.

4.1 Excel Files

The Excel files exported from S-PLUS were not in a format conducive to GUI development. Without this GUI, it would be very difficult for forecasters to effectively use the large amount of information in these situational climatologies. To put the data in a more presentable format for the forecasters, the AMU wrote Excel macros in Microsoft Visual Basic for Applications to merge the individual spreadsheets generated by S-PLUS into 45 monthly Excel 2010 workbooks per site. Each workbook contained a worksheet for each of the seven flow regimes with 1-, 3- and 6-hour interval tables displaying the number of days with NLDN CG lightning, the climatological probability of lightning and corresponding probability charts for all time intervals and at 5-, 10-, 20- and 30-NM ranges (Figure 9).

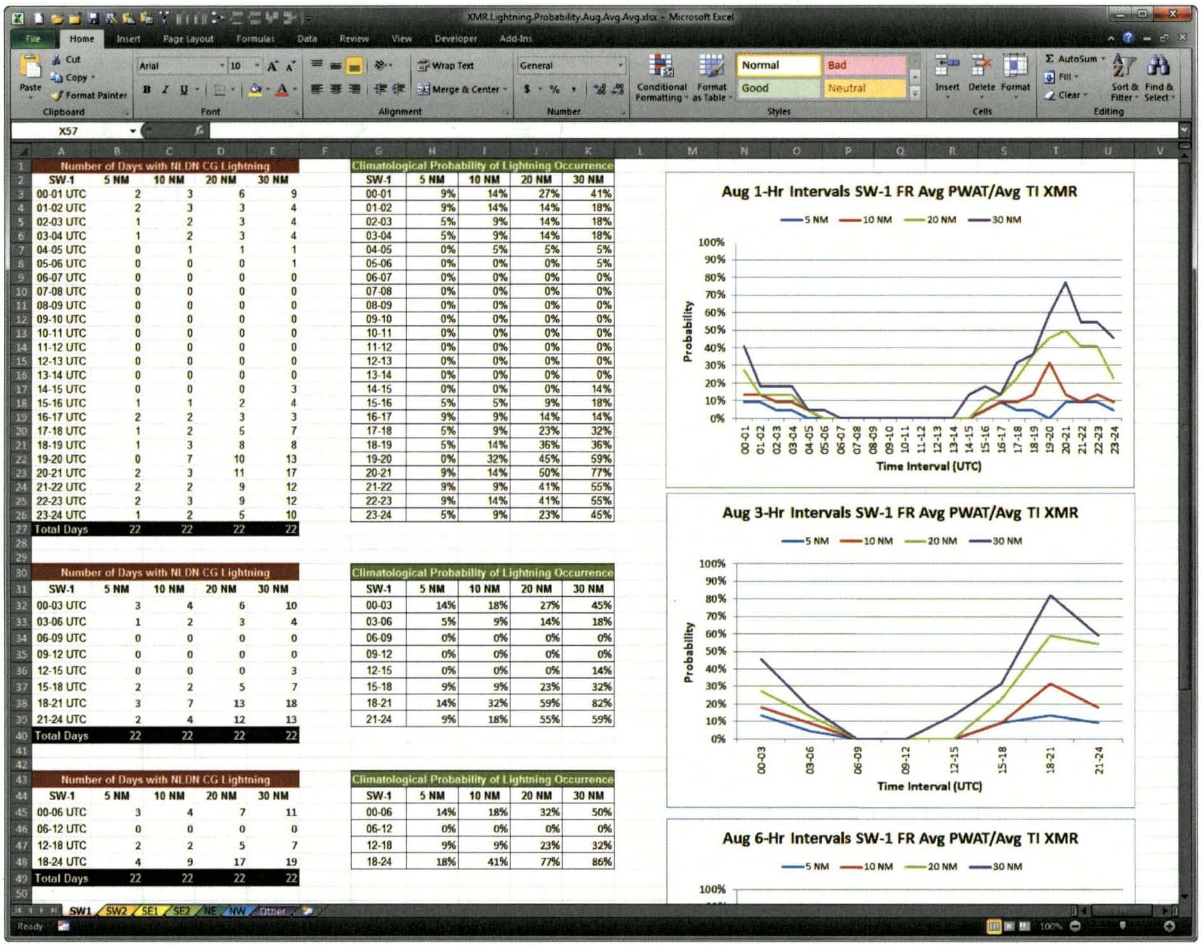


Figure 9. The XMR (CCAFS Skid Strip) Excel workbook showing the worksheet for Southwest-1 flow, average PWAT and average TI stratifications. Tables showing the number of days with lightning and climatological probability of lightning are on the left and center, respectively. The charts corresponding to the probability tables are on the right.

Each workbook contained 21 probability tables and 21 corresponding charts resulting in a total 34,020 tables and charts for all the sites combined. Although navigable in Excel, the AMU, NWS MLB

and SMG decided a web-based GUI would provide the best tool for quick and easy access to the data. Upon review of several workbooks, the AMU discovered some stratifications lacked sufficient data resulting in zero total days with lighting. Typically these were stratifications with a low PWAT and high TI or vice versa. However, PWAT/TI stratifications such as low/average, average/average and average/high did have sufficient data. Therefore, the AMU customers requested two GUIs – one with just the PWAT stratification and the other with both PWAT and TI. When the forecasters determine that the PWAT/TI GUI has insufficient data, they can revert to the PWAT-only GUI.

4.2 Web-based HTML GUI

The AMU developed a GUI[1] written in HTML that can be used in most web browsers. The home page of the GUI is shown in Figure 10 and presents the forecaster with an overview map of the thirty-six sites plus a drop-down navigation menu at the top of the page for navigation among the various stratifications. The AMU wrote the navigation menu code in the JavaScript language using Notepad++ software. The main navigation menu is displayed on every page of the GUI and provides the forecaster with access to each site and a help page.

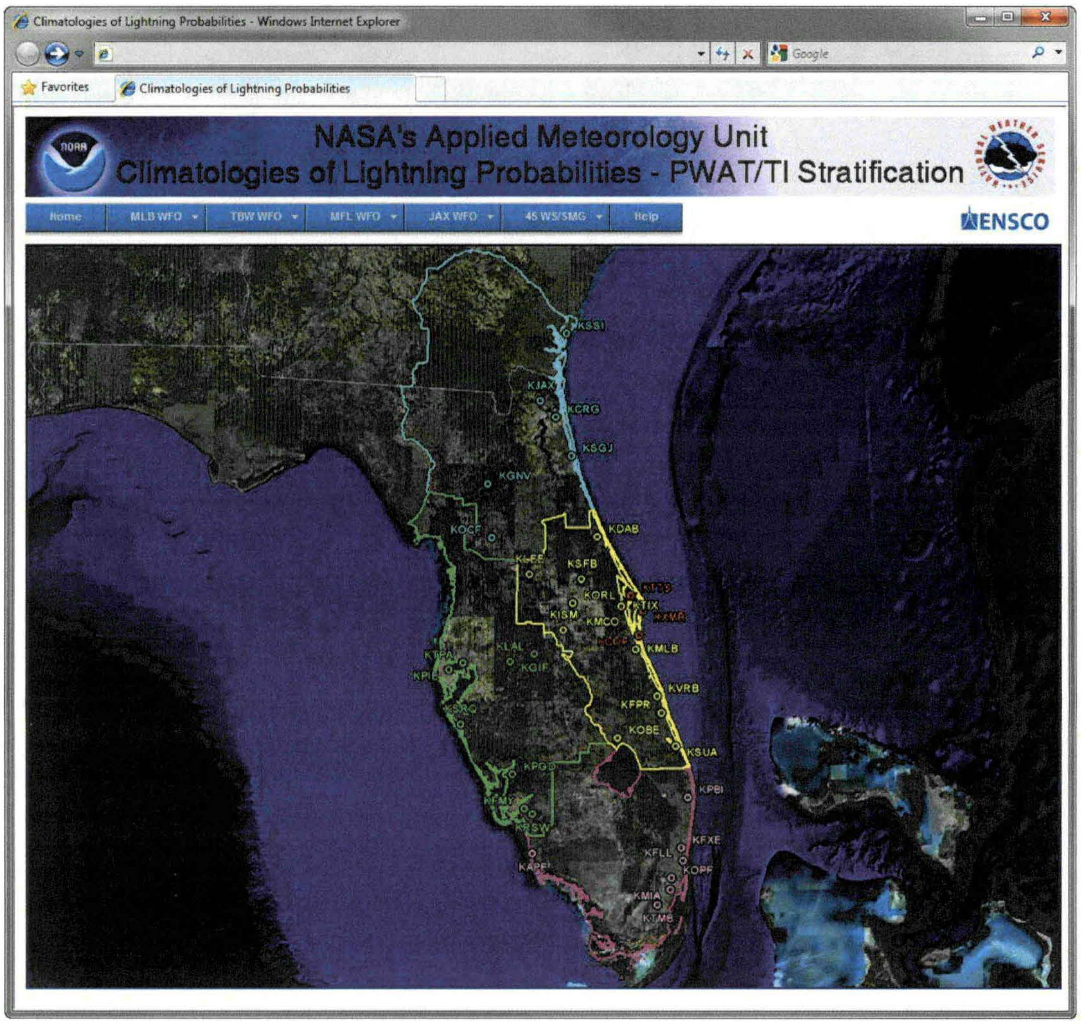


Figure 10. The home page of the Climatologies of Lightning Probabilities GUI displaying a map of the thirty-six sites and navigation menu at the top of the page.

[1] The GUI is available by request from the AMU at 321-853-8203 or via e-mail at amu@ensco.com.

The first level of the navigation menu at the top of the GUI displays links to the home page, the sites for each organization (four NWS Weather Forecast Offices and the 45 WS/SMG) and the help page. The sites associated with each organization are part of the first sub-menu. Figure 11 shows an example of a fully expanded drop-down menu from the menu bar for COF. To navigate to a particular data stratification, the user moves the mouse over the menu bar to choose an organization and a list of the sites drops down. Then the user moves the mouse over a site and the Month menu opens, followed by the PWAT stratification and then the TI stratification. The last menu displayed is for the 1-, 3- or 6-hr time interval or flow regime stratification.

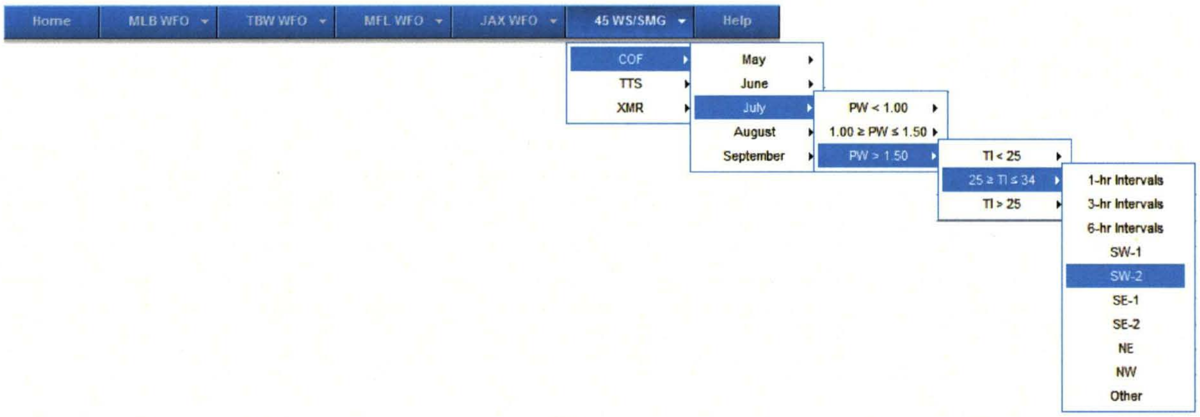
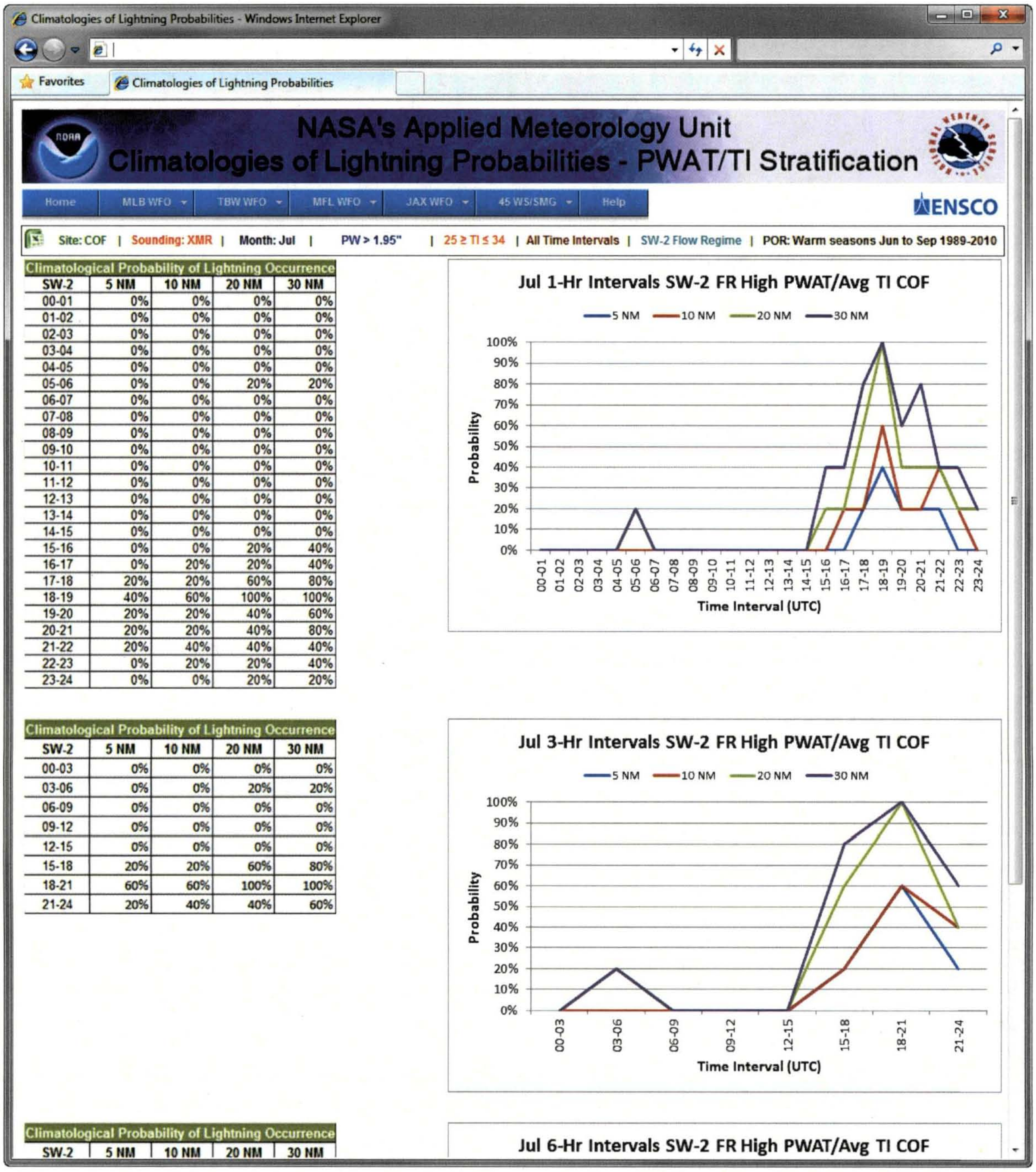


Figure 11. The menu bar used to navigate the GUI (blue bar at top) and an example of an expanded menu bar depicting navigating to COF during July for a high PWAT and an average TI for a SW-2 flow regime.

On the data pages within the GUI, directly below the navigation menu, there is a data bar showing the site, sounding location, month, PWAT range, TI range, time interval, flow regime and POR for the data displayed on the page (Figure 12). On the left side of the data bar is a Microsoft Excel icon that links the user to the spreadsheets containing the all of the data used to create the page being viewed. Each data page in the GUI shows tables of the climatological probabilities of lightning occurrence and a corresponding chart.



Climatological Probability of Lightning Occurrence

SW-2	5 NM	10 NM	20 NM	30 NM
00-01	0%	0%	0%	0%
01-02	0%	0%	0%	0%
02-03	0%	0%	0%	0%
03-04	0%	0%	0%	0%
04-05	0%	0%	0%	0%
05-06	0%	0%	20%	20%
06-07	0%	0%	0%	0%
07-08	0%	0%	0%	0%
08-09	0%	0%	0%	0%
09-10	0%	0%	0%	0%
10-11	0%	0%	0%	0%
11-12	0%	0%	0%	0%
12-13	0%	0%	0%	0%
13-14	0%	0%	0%	0%
14-15	0%	0%	0%	0%
15-16	0%	0%	20%	40%
16-17	0%	20%	20%	40%
17-18	20%	20%	60%	80%
18-19	40%	60%	100%	100%
19-20	20%	20%	40%	60%
20-21	20%	20%	40%	80%
21-22	20%	40%	40%	40%
22-23	0%	20%	20%	40%
23-24	0%	0%	20%	20%

Climatological Probability of Lightning Occurrence

SW-2	5 NM	10 NM	20 NM	30 NM
00-03	0%	0%	0%	0%
03-06	0%	0%	20%	20%
06-09	0%	0%	0%	0%
09-12	0%	0%	0%	0%
12-15	0%	0%	0%	0%
15-18	20%	20%	60%	80%
18-21	60%	60%	100%	100%
21-24	20%	40%	40%	60%

Climatological Probability of Lightning Occurrence

SW-2	5 NM	10 NM	20 NM	30 NM

Figure 12. An example of a data page for COF from the GUI. The blue navigation drop-down menu is located directly below the title banner. The data bar is below the navigation menu and it shows (from left to right) the site, sounding location, month, PWAT range, TI range, time interval, flow regime and POR for the data. Data tables containing the climatological probability of lightning occurrence are located on the left side of the page and their corresponding charts are on the right side of the page.

5. Summary and Conclusions

The AMU added three years of data to the POR from the previous work resulting in a 22-year POR for the warm season months from 1989-2010. In addition to the flow regime stratification, moisture and stability stratifications were added to separate more active from less active lighting days within the same flow regime. The parameters used for moisture and stability stratifications were PWAT and TI which were derived from sounding data at four Florida radiosonde sites. Lightning data consisted of NLDN CG lightning flashes within 30 NM of each airfield. The AMU increased the number of airfields from nine to thirty-six which included the SLF, CCAFS, PAFB and thirty-three airfields across Florida. The NWS MLB requested the AMU calculate lightning climatologies for additional airfields that they support as a backup to NWS TBW which was then expanded to include airfields supported by NWS JAX and NWS MFL. The updated climatologies of lightning probabilities are based on revised synoptic-scale flow regimes over the Florida peninsula (Lambert 2007) for 5-, 10-, 20- and 30-NM radius range rings around the thirty-six airfields in 1-, 3- and 6-hour increments.

The lightning, flow regime, moisture and stability data were processed in S-PLUS software using scripts written by the AMU to automate much of the data processing. The S-PLUS data files were exported to Excel to allow the files to be combined in Excel Workbooks for easier data handling and to create the tables and charts for the GUI.

The AMU revised the GUI developed in the previous phase (Bauman 2009) with the new data and provided users with an updated HTML tool to display and manipulate the data and corresponding charts. The tool can be used with most web browsers and is computer operating system independent. The AMU delivered two GUIs – one with just the PWAT stratification and one with both the PWAT and TI stratifications due to insufficient data in some of the PWAT/TI stratification combinations. This will allow the forecasters to choose a moisture-only or moisture/stability stratification depending on the flow regime and available data.

The results of updating the previous phase of this work will produce a better operational product because:

- The POR was increased by three years,
- The PWAT moisture parameter was added,
- The TI stability parameter was added, and
- The capability was provided to other NWS offices in Florida.

6. Future Work and Potential Improvements

6.1 Sounding Sites

The AMU used the closest sounding site to each airfield to determine the moisture and stability stratifications at those airfields. A better technique for future work might be to determine the prevailing low-level wind flow at each airfield for each day in the POR and use the closest upwind sounding to determine the stratifications. This technique could have an impact on the lightning climatologies for airfields located about half-way between sounding sites and less impact for those airfields close to a sounding site.

6.2 Improved Stability Stratification

The TI stratification was chosen primarily based on previous AMU work but also from 45 WS experience. The previous work only provided the TI thresholds for the entire warm season and was based on the XMR sounding. In future work, the TI stratification could be improved by determining a threshold for each month during the warm season and for each sounding site similar to how the AMU determined the PWAT moisture stratification.

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List of Acronyms

14 WS	14th Weather Squadron
45 WS	45th Weather Squadron
AMU	Applied Meteorology Unit
CCAFS	Cape Canaveral Air Force Station
CG	Cloud-to-Ground
CSR	Computer Sciences Raytheon
CSV	Comma Separated Value
CWA	County Warning Area
ESRL	Earth System Research Laboratory
GUI	Graphical User Interface
HTML	Hyper-Text Markup Language
JAX	Jacksonville, FL radiosonde 3-letter identifier
KI	K-Index
KSC	Kennedy Space Center
LI	Lifted Index
mb	Millibar
MFL	Miami, FL radiosonde 3-letter identifier
NLDN	National Lightning Detection Network
NM	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
NWS JAX	National Weather Service Jacksonville, FL
NWS MFL	National Weather Service Miami, FL
NWS MLB	National Weather Service Melbourne, FL
NWS TBW	National Weather Service Tampa, FL
PAFB	Patrick Air Force base
POR	Period of Record
PWAT	Precipitable Water
SLF	Shuttle Landing Facility
SMG	Spaceflight Meteorology Group
SOO	Science and Operations Officer
TAF	Terminal Aerodrome Forecast
TBW	Tampa, FL radiosonde 3-letter identifier
TI	Thompson Index
XMR	CCAFS radiosonde 3-letter identifier

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14. ABSTRACT

The threat of lightning is a daily concern during the warm season in Florida. Research has revealed distinct spatial and temporal distributions of lightning occurrence that are strongly influenced by large-scale atmospheric flow regimes. Climatologies included the probability of lightning at 36 airfields in peninsular Florida at 5-, 10-, 20- and 30-NM distances from the center point of the runway at each site and the climatologies were stratified by flow regimes with probabilities depicted at 1-, 3-, and 6-hr intervals. Three years of data were added to the previous work resulting in a period of record for the warm season months (May-Sep) from 1989-2010. A moisture stratification based on precipitable water (PWAT) and a stability stratification based on Thompson Index (TI) derived from sounding data at four Florida radiosonde locations were added to the climatology for this phase of the work. Larger PWAT and TI values represent a more unstable atmosphere. The moisture and stability stratifications were added to separate more active from less active lighting days within the same flow regime. The results were presented in tabular and graphical format and incorporated into a web-based GUI so forecasters could easily navigate through the large amount of data.

15. SUBJECT TERMS

Lightning, Climatology, Climatological, Statistics, Probability of Lightning, Space Shuttle, Weather, Meteorology, Shuttle Landing Facility, Flight Rules, Weather Flight Rules, National Weather Service

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